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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/40000741
Canadian Building Digest, 1982-03-01

Canadian Building Digest
Division of Building Research, National Research Council Canada

CBD-222

Airtight Houses and Carbon Monoxide Poisoning

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Originally published March 1982.

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The Problem

The operation of an air exhaust system or a fuel-burning appliance removes the air from a house, thereby creating a slight negative pressure inside the house. If too much air is removed, the negative pressure can become large enough to reverse the natural flow of gases up the furnace chimney and instead cause the chimney to become a passageway for the supply of outside air into the house. If the furnace burner is operating at that time, its products of combustion will not be able to escape through the chimney and will enter the house instead through the draft regulator on the venting system. This action may create a danger of carbon monoxide poisoning for the inhabitants.

As part of the national energy conservation program, air leakage into houses is being reduced by improved construction techniques for new houses and by the caulking and sealing of existing houses. There is concern, however, that the improved airtightness may increase the risk of carbon monoxide poisoning or asphyxiation.

Evidence of the Problem

Gas utilities and other authorities have recently expressed concern about the number of complaints from homeowners of gas odours in their houses and about the growing incidence of carbon monoxide poisonings. The poisonings are thought to be associated with insufficient air infiltration into houses and are usually connected with the operation of fireplaces. The gas odours, it is believed, are the result of an inadequate air supply into the house.

Central records show that in Canada each year about 10 people die and about 100 people receive hospital in-patient treatment as a result of carbon monoxide poisoning attributed to the incomplete combustion of domestic fuel. These records, however, do not establish a direct connection between the carbon monoxide problems and inadequate air supply or venting failure of the furnace chimney. It is possible, therefore, that some of the poisonings have been caused by chimney blockage or other factors not related to the airtightness of the house. Since central records are not kept of people treated by hospital emergency departments, in doctors' offices or by police or fire services, the figures for carbon-monoxide-related incidents remain incomplete.

The service call records of one gas distributor revealed various reasons for odour complaints, such as vapour from gasoline stored near the furnace, leaks in gas piping and extinguished pilot flames. Occasionally, gas odours that may have resulted from insufficient ventilation while the house was closed and unoccupied were not detectable after people had entered and moved about in the house. There was insufficient information to determine how many of the gas odour complaints could be directly linked to the airtightness of houses.

Although the problem of carbon monoxide poisoning does not appear to be widespread, the problem does exist. The following analysis was undertaken to determine to what extent carbon monoxide poisoning could be related to the airtightness of a house.

Possible Cause of the Problem

Recently-constructed houses are, in most cases, more tightly constructed than older houses. Smaller houses and row houses with one or more enclosing surfaces common to adjoining buildings have less exterior surface area through which air infiltration can occur. The smaller leakage area, combined with improved construction practices such as the use of tighter windows, weather stripping and caulking all tend to reduce the amount of air leakage in newer houses. The increased airtightness of these houses may cause venting failure of the chimney, which can lead to carbon monoxide poisoning.

Air Leakage Rate

The airtightness of a house can be measured by sealing intentional exterior openings and exhausting air from the house using a calibrated fan. Measurements for a number of typical new Canadian houses showed that the air leakage rate for the most airtight house was two air changes per hour under a test pressure difference of 50 Pa (0.2 in. of water).

In order to provide numerical values for this analysis, a house was invented that had the above air leakage characteristics and that was the size of an average new Canadian house. It was given a floor area of 100 m² (1,060 sq ft) and a volume of 480 m³ (17,000 cu ft). Figure 1 indicates the air leakage rates at various pressure differences for this house.

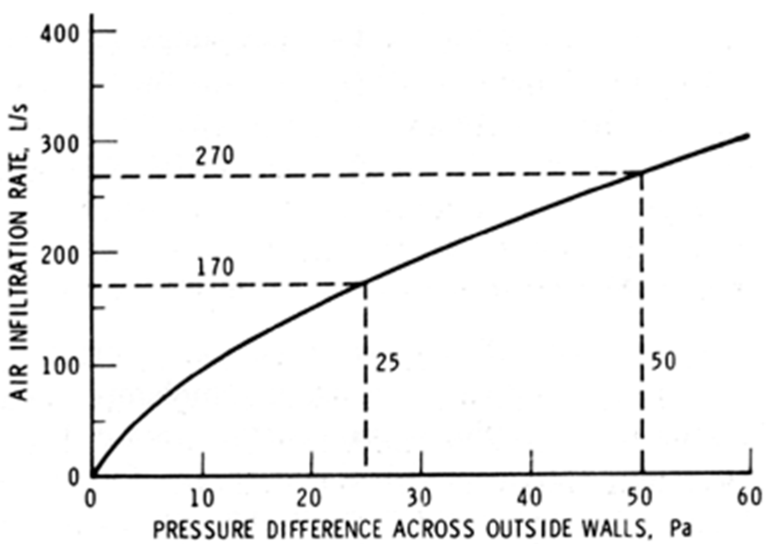

Figure 1. Air leakage characteristics of an airtight house.

Negative Pressure

The natural draft, or negative pressure, created in a chimney causes the flow of gases up the chimney and can be overcome most easily when that draft is lowest. The draft created at the base of a chimney depends upon many variables, one of which is the inverse of the outside air temperature. With other variables held constant, a lower natural draft will occur at higher outside air temperatures. In this analysis, it is assumed that furnaces and fireplaces will be used until the outside air temperature reaches a maximum of 15°C (60°F). It is at this temperature, then, that the lowest natural draft will occur. At 15°C, a furnace in operation can create a draft at the bottom of its chimney of 25 Pa (0.1 in. of water), assuming a chimney height of 6 m (20 ft) and a flue gas temperature in the furnace chimney of 150°C (300°F). In the case of a fireplace in operation, the flue gas temperature can reach or exceed 800°C (1,500°F), creating a draft in excess of 50 Pa (0.2 in. of water) at the base of the fireplace chimney. (Here also, the chimney is assumed to be 6 m high and the outside air temperature, 15°C.) The larger negative pressure created when the fireplace is in use can overcome the natural draft of the furnace chimney and cause a flow of outside air down the furnace chimney. This, in turn, prevents the escape of carbon monoxide and other flue gases to the outdoors, forcing them instead through the draft regulator into the occupied space of the house. However, if there is a sufficient supply of air into the house, as a result of either leakage or intentional openings, to meet the demand of the fireplace, draft failure at the furnace chimney may not occur.

Since an exhaust fan can also cause a draft failure at the furnace chimney, the interior should be supplied with enough outdoor air while the exhaust fan is operating to prevent this.

If the negative pressure reaches 25 Pa in the house considered in this analysis, 170 L/s (360 cfm) of outside air will leak into the house (according to Figure 1). If the total air demand at any time does not exceed 170 L/s, there should be no downdraft at the furnace chimney.

Air Demand

In general, 30 litres of air are needed for each litre of gas burned: half for the combustion process and the other half for dilution at the draft regulator in order to maintain a relatively constant draft at the vent outlet of the furnace. Normally, a furnace would be rated for an input of 0.8 L/s (100 cu ft/hr) of gas and would require 24 L/s (50 cfm) of air during burner operation. A similar amount of air would be needed for a domestic oil burner of equivalent heating capacity.

A fireplace normally burns about 5 kg (10 lb) of seasoned wood per hour, producing flue gases which may contain as little as 1% carbon dioxide. Under these conditions the fireplace would consume 110 L/s (240 cfm) of room air. Many factors, such as the fuel consumption rate and flue gas temperature, vary while a fireplace is in use. These factors affect its air consumption rate so that the 110 L/s demand is not constant during its operation. Although the air demand may exceed or fall short of this amount for brief periods of time, 110 L/s represents a reasonable estimate of the amount of air needed during the operation of a fireplace.

The quantity of air moved by kitchen exhaust fans, toilet exhaust fans and clothes dryer fans varies considerably, depending upon the type and model of fan used and the length and size of the exhaust duct. Average air requirements are: 70 L/s (150 cfm) for kitchen exhausts, 20 L/s (50 cfm) for toilet exhausts and 65 L/s (135 cfm) for dryer exhausts[1]. If any of these systems are operating when a downdraft is being created in the furnace chimney, they will have to operate against the additional negative pressure (at least 25 Pa) creating the downdraft, thereby causing the volume of exhaust air to decrease to approximately 55 L/s (120 cfm) for kitchen exhaust fans, 12 L/s (25 cfm) for toilet exhaust fans and 55 L/s for dryer fans.

At 25 Pa negative pressure, the total air requirement for the furnace, fireplace and exhaust systems of the house used in this analysis is approximately 260 L/s (560 cfm). Since only 170 L/s (360 cfm) are provided by air leakage into the house, there will be an expected deficiency of about 90 L/s (200 cfm) at times when all the systems operate simultaneously. A downdraft in the furnace chimney could be created to supply this deficit. If there is no fireplace in the house or if the fireplace is not in use, the normal air leakage into the house should be enough to meet the needs of the furnace and exhaust fans, thus eliminating the possibility of a downdraft at the furnace chimney. The actual deficiency in a house at a given time depends upon the number of operating systems, the air exhaust rate of each system and the leakage characteristics of the house. Because all systems usually do not operate simultaneously, the maximum deficiency may not occur very often.

Possible Cures

The risk of carbon monoxide poisoning caused by a downdraft in a furnace chimney can be eliminated by separating the furnace from the occupied space of the house and by supplying outside air for combustion and dilution directly into the furnace room. This will ensure that the furnace does not have to compete for the limited amount of air leaking into the house. The problem can also be prevented by using a direct vented furnace in which the combustion process is isolated from the occupied space of the house and is connected directly to the outdoors. The initial costs for either of these solutions are generally high.

A solution with lower installation costs is to provide an intentional opening to the exterior for the supply of outside air. Although this modification introduces more outside air and requires more energy consumption for heating, it does ensure the safe operation of fuel-burning equipment. This solution can be implemented in a variety of ways. One means of supplying outside air is to duct it directly into the fireplace, at the same time providing a damper to stop the supply of air when the fireplace is not in use. Another method consists of supplying outside air through a wall opening into the basement space; however, this approach may result in unacceptably low temperatures in the basement. A third method, which requires installing a supply air duct from outdoors to the return air plenum of the warm-air heating system, ensures more acceptable comfort conditions. One problem with these air supply systems is that the air supply cannot be regulated. Too much air may be forced into the house if the wind blows into the opening; and not enough, if the wind blows from the opposite direction.

Costs

It costs approximately $100 to install, during construction, a short length of thermally insulated duct from the outdoors to the return air plenum of a furnace. (An air supply into a fireplace located on an outside wall may be less expensive.) At current lending rates, a $100 increase in the mortgage may incur an extra cost of $15 per year for repayment.

The costs to heat the air supply must be considered also. The free area required for a supplemental air supply system in the house used in this analysis was calculated to be 260 cm^2 (40 sq in.). This is about 28% of the average 930 cm^2 (144 sq in.) leakage area already existing in most houses. This air supply system would, in turn, increase by 28% both the amount of air infiltration and the heating costs associated with it. Assuming that about 30% of the annual heating cost is due to air infiltration, the intentional opening would therefore increase annual heating costs by about 8% in the sample house. Using a damper to stop this supplemental air supply when the fireplace is not in use would eliminate or considerably reduce the 8% increase in heating costs.

Detection of Potential Air Supply Problems

This Digest has focused on the problems presented by fireplaces since, of all the fuel-burning space heaters, fireplaces are usually the most difficult to regulate with respect to air consumption. Wood stoves and other fuel-burning space heaters can have similar effects on the air demand of a house, especially if they are operated with substantial air openings or high flue gas temperatures. The supply of an adequate amount of outside air should be considered for all fuel-burning appliances.

A potential risk of carbon monoxide can be determined using the following simple test. Although this test may be performed at any time, potential problems under the most adverse conditions can be detected if it is performed in mild weather when draft failure of the furnace chimney is most likely to occur. After closing the doors and windows of the house, start a substantial fire in the fireplace and switch on all the air exhaust systems in the house. Once this is done, light a cigarette or other type of smoke generator, hold it near the draft regulator of the furnace and note whether the smoke enters the flue pipe. If it does not or if it is blown back into the occupied space, this indicates a venting failure of the furnace chimney and a potential carbon monoxide problem if the furnace is operated under these conditions. Then open a window to provide additional outside air and repeat the test to determine if this will correct the problem. Occupants who are aware of a potential carbon monoxide problem can always take safety precautions by opening a window when using the fireplace. A more satisfactory solution, however, is to install a permanent outside air opening connected to a duct having an air outlet near or in the fireplace.

If a space heater is used, it may not be possible to connect an outside air supply duct to the heater, and providing the supply directly into the space containing the heater may lead to uncomfortably low temperatures. In that case the required supply of outside air should be ducted into the return air plenum of the furnace. A manual damper in the air supply duct that permits air to be admitted only when needed will reduce or eliminate the increased heating cost but can lead to air starvation and a resulting risk of carbon monoxide if the occupant forgets to open the damper when necessary.

Reference

1. "Design of a Mechanical Ventilation System for Future Tightly Constructed Residential Homes" by F. Perricone, 0ntario Hydro Report No. 78-411-K, Toronto, 1978.